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TITLE: High temp. resistant solder connection enabling mechanically stable, elastically deformable connection of semiconducting body to cooling body

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ABSTRACT:

CHG DATE=20020503 STATUS=O>The solder connection has a metal coating (7) of

copper or nickel between a semiconducting body (1) and a connected cooling body

(11). The metal coating has a foam-like linked structure with hollow spaces (9) enclosed by dividing walls that extend without interruption between the semiconducting body and the cooling body.

Translation of German DE 100 15 962 A1

Description

The present invention relates to a high temperature resistant solder connection made of a metallic layer which is provided between a semiconductor body and a cooling body connected thereto.

Power semiconductor construction elements develop substantial quantities of heat when operating, the heat causing substantial increases in temperature, which can lead to damage in the power semiconductor construction elements. For this reason, power semiconductor construction elements are provided with cooling bodies that absorb the heat developed in the power semiconductor construction elements.

Power semiconductor construction elements are normally made of silicon, whereas copper is preferred for the cooling body.

If now a silicon power semiconductor construction element is provided with a copper cooling body, the different coefficients of thermal expansion of silicon and copper will produce thermal mismatches between the power semiconductor construction element and the cooling body, which will in turn lead to large mechanical stresses which can result in cracks and failures in the semiconductor body.

Over many years, the solution to this problem has been intensively investigated. In this connection it is to be noted that the power semiconductor construction element has been placed as close as possible to the cooling body, in order to ensure good heat conduction to the cooling body. On the other hand, however, a predetermined minimum spacing between the power semiconductor construction element and its cooling body has been thought necessary, so that the connection layer could absorb the shear forces resulting from a distortion of the power semiconductor construction element and its cooling body.

Up to now, use has been made of expanded ceramic/copper substrates (DCB-substrates), against which a silicon power semiconductor construction element has been applied using a lead-tin soft solder connecting layer, and which can be optionally provided with an additional copper cooling body on the side facing the power

semiconductor construction element. The soft solder connecting layer reacts to any arising mechanical shear stresses by undergoing plastic deformation, and thus contributes to the reduction of such shear stresses.

Although the DCB-substrates are thermally matched with silicon, this solution to the above-described problem has particular disadvantages: due to the DCB–substrate and the lead-tin soft solder connecting layer, the conduction of heat away from the power semiconductor construction element is reduced. Moreover, the soft solder connecting layer cannot withstand higher operating temperatures in the region of 200°C, which at present are occasionally encountered in the electronics field, since soft solder begins to flow (soften) in this temperature range.

In order to ensure stability and operating reliability at higher temperatures, the so-called diffusion solder connections between a power semiconductor construction element and a cooling body, in particular a DCB-substrate, are occasionally used. However, in such diffusion solder connections, the solder seam or joint is hard and extremely thin, so that the arising mechanical stresses cannot be reliably equalised, and a failure in the power semiconductor construction element cannot be ruled out.

At present there is utilized as a connecting layer, also called an "interposer", between a power semiconductor construction element and a cooling body, preferably either a soft solder layer of about 100 μm in thickness, or an equally thick organic layer made of plastic. The term "power semiconductor construction element" can be taken to mean also an integrated switch, while a cooling body can enclose the plate or board of the power semiconductor construction element.

As already mentioned above, such a soft solder layer is unsuitable for use in temperature ranges of 200°C and higher, whereas an organic layer is not very suitable for heat conduction.

Therefore it is an object of the present invention to provide a mechanically stable, elastically deformable, high-temperature resistant solder connection between a semiconductor body and a cooling body connected thereto; furthermore there is provided a process and an apparatus for the creation of such a solder connection.

In accordance with the invention, this object is attained utilising a heat-resistant solder connection of the kind mentioned earlier, wherein the metal layer has a foam-like

linked structure with hollow spaces enclosed by dividing walls that extend without interruption between the semiconductor body and the cooling body.

The solder connection in accordance with the invention, made of a metal layer with a foam-like linked structure, provides a flexible intermediate layer ("inter-poser") between the semiconductor body and the cooling body, which reduces mechanical stresses arising at higher temperatures and at the same time has an excellent heat conductive capacity. The solder connection in accordance with the invention can be introduced into the wafer plane between the semiconductor body and the cooling body, so that use of solder bands is not necessary.

The creation of the high temperature solder connection in accordance with the invention is undertaken as follows:

On the rearward side of a silicon wafer, from which in a later method step a plurality of semiconductor construction elements will be obtained, a thin metal film, for example made of copper, is applied by galvanic deposition. This thin metal film, whose thickness is in the region of a few μms, functions as a starter layer for a subsequent galvanic deposition. It is to be understood that the wafer can consist of a material other than silicon, and that likewise a material other than copper can be used for the metal film.

To the metal film there is then adhered a thin lamina about 100 μm thick, which is preferably of plastic, and which has an open-pore structure. This lamina is preferably self-adhesive or coated on one side with an adhesive. The pores of the lamina have preferably a diameter in the region between 5 and 20 μm, and are connected with one another.

The wafer, thus prepared, is then metallized in a galvanic bath with, for example, copper or nickel. During this metallization there is growth of the metal, in particular copper or nickel, in the region of the pores on the thin metal film (likewise of copper and/or nickel, for example) to form a metallic foam which breaks through the plastic in many locations, whereby the pores of the lamina filled with the metal interlink with each other, the walls of the layer however simultaneously preventing the metal layer from growing together in a compact manner.

As a result of the relatively small volume of the walls of the lamina, by comparison with the volume of the pores, the growing metal layer is preponderantly of

solid metal, interrupted by the plastic walls of the lamina. Due to the galvanic process and the three dimensional linkage of the growing metal layer, it is guaranteed that this growing metal layer will not be interrupted in the vertical direction. In other words, there is guaranteed a high heat conductivity and a good electrical conductivity in the vertical direction in the growing metal layer between the semi-conductor body and a cooling body. The metal layer does not necessarily have to grow as far as the upper edge of the lamina. Instead, its thickness depends on the subsequent use of the semi-conductor, and can lie between 10 and 30 μm.

Following the above described galvanic process, the lamina is preferentially removed using a suitable solvent. This can be done directly, since the walls of the lamina, like the pores, form an interlinked, upwardly open frame.

The metal layer thus constituted can now be directly soldered, i.e. be provided with a solder layer. This solder layer should be relatively thin, with a layer thickness in the region of about 2.5 μm, so that the pores of the grown metal layer do not close.

A suitable soldering process is the already mentioned diffusion soldering, in which a low-temperature process creates very high temperature-resistant compounds.

The thin solder layer can also be applied to the metal layer by, for example, a galvanic process, currentless deposition, thermal vaporisation or sputtering of pure zinc or of an alloy with an even lower melting temperature, such as eutectic tin/indium. This can take place, especially in bulk processes, even ahead of the removal of the lamina.

Instead of a plastic lamina, one could also use ceramic materials, foams of which are known having a substantial open pore structure. In other words, with this variant, a foam based on a ceramic working material is deposited as a dielectric layer on the wafer, and in the same manner as the plastic layer, has its pores galvanically filled. This ceramic foam, after the filling with metal, in particular with copper and/or nickel, should not be removed, since it has the required high temperature resistance. In this case the metal filling can grow to a point even above the upper edge of the layer formed by the ceramic foam, resulting ultimately in a closed surface.

The high temperature-resistant solder connection according to the invention can also, using structured surfaces – for example contact pads or contact cushions – be applied to accomplish the metallization. For this, the open-pore lamina (or a ceramic foam) is adhered to the already structured surface, or deposited thereon. For

metallisation intended to form the metal layer with the foam-like interlinked structure, no further galvanic process can be used, since the continuous conductive metal layer is lacking in copper or nickel in particular. Through the currentless deposition of special nickel, the lamina or the ceramic foam can be filled selectively only in the region of the contact pads. Attention is drawn to the fact that nickel, just as with copper, is appropriate for diffusion soldering.

Another possibility for creating the foam-like, interlinked structure for the metallic layer involves applying plastic balls to the metal film, and filling with metal the space between the balls. In this process, balls of differing sizes are used, so that after the balls are removed, the resulting pores are of sizes which vary between the semi-conductor body and the cooling body. The balls should be made of a material which cannot be galvanised and which easily precipitates – so that the balls sink readily to the bottom in a corresponding galvanising apparatus.

Such a galvanising apparatus is preferably provided with a stirrer which readily tumbles the balls. After the stirrer is turned off, the balls are placed on the metal film of the wafer, whereupon the larger balls – due to their greater weight – sink downward. As soon as the balls are stored on the wafer, the galvanic process begins, in order to fill the spaces between the balls with metal, in particular copper or nickel.

The invention is described in greater detail below, utilising the drawings.

Fig. 1 shows a schematic sectional view of a wafer, having a metal film and a lamina partly filled with copper;

Fig. 2 is a schematic sectional view for explaining a structurized metallisation on contact pads;

Fig. 3 is a schematic sectional view, helpful in explaining the recovery of a foam-like linked structure with balls; and

Fig. 4 is a schematic view of an apparatus for creating the foam-like linked structure utilizing balls.

On a wafer 1 made of silicon or another semiconductor material such as silicon carbide or an AIII-BV-compound, there is applied a metal film 2 made of copper or nickel, with a layer thickness of 100 nm up to a few μm, as the foundation layer. Upon this metal film 2 an open-pore lamina 3 is applied which consists of plastic, for example

polymer, or a ceramic. This open-pore lamina 3 has a foam-like structure with hollow spaces 4 and with plastic or ceramic regions 5.

The hollow spaces 4 are interconnected, so that the desired open-pore structure is present, whereas the regions 5 are likewise linked to one another. This linkage can take place in various planes, by the connections of region 5. Since Figure 1 shows merely a section in a predetermined plane, the linkage of region 5 is not visible.

The metal film 2 can be applied using galvanic deposition. The lamina 3 is preferably adhered to the metal layers 2, which is why it is coated on the side facing the metal layer 2 with a self-adhesive, or can itself be self-adhesive. The pores or hollow spaces 4 have a diameter in the range between 5 and 20 μm and are all connected with one another.

The wafer 1, prepared in this manner with the metal film 2 and the lamina 3, is then metallized in a galvanic bath with, for example, copper or nickel. This causes the metal to "grow" in the region of the hollow spaces 4, to provide a multiply discontinuous metallic foam 6, whereby the hollow spaces filled with metal link up with each other, and the regions 5 of the lamina 3 prevent any of the metal layer 7 formed by the foam 6 from growing together in a compact structure.

Due to the small volume of the region 5 in comparison to the volume of the hollow cavities (4), the metal layer 7 is preponderantly made of metal. Moreover, it is guaranteed, due to the galvanic process and the three-dimensional linking of the foam of the metal layer 7, that this metal layer 7 will be free from breaks in the vertical direction. In addition, there is guaranteed both a high heat conductivity as well as a good electrical conductivity in the metal layer in the vertical direction between the semiconductor wafer 1 and a cooling body which is coated on the surface of the metal layer that is directed toward the semiconductor wafer 1, utilizing a thin solder layer having a thickness from 2 to 5 μm.

The metallic layer 7 is not required to extend as far as the upper corner of the lamina 3. Rather, its thickness depends upon the subsequent use of the semiconductor construction element, and may lie between 10 and 100 μm, preferably 10 and 30 μm.

Following the galvanic process, the lamina 3 is removed using a suitable solvent means, such as acetone, this being now possible since the regions 5 of the lamina 3, similarly to the hollow spaces 4, provide a cohesive, upwardly open framework.

Figure 2 shows a further example embodiment of the solder connection in accordance with the invention, in which the lamina 3 is applied to a surface of the semiconductor-wafer 1, the surface being provide with contact pads 8. In this example embodiment, the continuous metal film 2 is not present. Since this continuous, conductive base layer is absent, no galvanic process can be undertaken with a view to creating metal foam 6 on the contact 8. A thin continuous starter layer can subsequently be removed by applying a brief aqueous etching step, whereby the considerably thicker pads will not be attacked.

However, by the deposition of, for example, nickel in the absence of flowing current, it is possible to selectively fill the lamina 3 with the metallic layer 7 only in the region of the contact pads 8.

Figure 3 shows a further example embodiment of the heat resistant solder connection in accordance with the invention. In this example embodiment, the "layer" 3 is constituted by spheres or grains 9 or spherical structures of varying sizes, which are deposited on the metal film 2. The cavities 4 between the spheres 9 are filled with metal as in the example embodiment of Figure 1, so that a coherent metal layer 7 is created.

After the manufacture of the metal layer 7, the spheres 9 are removed using a suitable solution, which can be done immediately since the spheres 9 contact each other and thus provide a coherent framework. Finally, there is provided on the metal layer 7 yet another thin solder layer 10 having a layer thickness of 2 to 5 μm, to which a cooling body 11, made for example of copper, can be brought into juxtaposition.

Removal of the layer 3 or the balls 9 is not essential if for these a heat-resistant material is used, for example ceramic, glass or semiconductor (Si).

Figure 4 shows yet another apparatus for making the high-temperature solder connection of Figure 3: in a galvanic bath 12 there is provided a stirrer which causes the balls 9 to undergo initial turbulent motion, subsequently settling against the metal film 2 when the stirrer 13 is shut off.

By the use of spheres of differing sizes, a corresponding structuring of the metal layer 7 can be attained, since the smaller balls will preferentially collect in the lower spaces between the downward sinking larger balls. After turning off the stirrer 13, the galvanic deposition of copper or nickel in order to provide the metal layer 7 is initiated.